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by

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SINGLE-TRANSVERSE-MODE, NARROW-BANDWIDTH PULSED TUNABLE DYE LASER WITH HOLLOW CIRCULAR INTRACAVITY DIELECTRIC WAVEGUIDE

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Abstract: This paper presents a tunable, narrow-bandwidth pulsed dye laser with hollow circular intracavity waveguide and grazing-incidence grating. The experimental results show that the laser system can have an output with single transverse mode, narrow bandwidth, and high-efficient laser. The paper analyzes the design mechanism of the system.

Key words: hollow circular waveguide, grazing-incidence grating, narrow bandwidth pulsed dye laser.

Since narrow-bandwidth tunable dye lasers have wide applications in physics, chemistry, and biology, researchers employed various methods to control the output mode of pulsed dye lasers in order to obtain high-quality output of narrow bandwidth laser oscillations [1-3]. The paper reports on a new design: a circular hollow waveguide is added to a conventional Littman

resonance oscillator [4]. As indicated by the measurement results in the experiments, when compared to conventional Littman resonant oscillation cavities, there are striking improvements in the output parameters of this laser system with respect to energy, mode, and bandwidth.

I. Design Concept

For the conventional structure of a Littman resonant oscillator cavity, the following relationships are in effect [4,5]:

$$\Delta\lambda = \frac{2\sqrt{2}\lambda}{\pi L m}a, \quad \frac{L\cos\theta}{2d} = \frac{\lambda}{\pi\omega}, \tag{1}$$

In the equation, $\Delta\lambda$ is the laser output bandwidth of the cavity; ω is the radius at the waist of the light beam; and d is the distance between the grating center (at grazing incidence) and the dye pool. From Eq. (1), under conditions of a certain grating constant a, diffraction level number m, and wavelength λ, the laseroutput band will be narrowed by increasing the lighting width (L) of the grating. However, in order to obtain a large L, we should allow $\cos\theta \to 0$; the grating incidence angle θ approaches 90°. At this stage, the diffraction loss in the laser cavity will grow rapidly. As shown in Fig. 1, the spectral bandwidth of the system is

$$\Delta\lambda = [(\Delta\lambda_\lambda)^2 + (\Delta\lambda_a)^2]^{1/2} = \left[\left(\frac{\partial\lambda}{\partial\theta_1}\right)^2 (\Delta\theta_1)^2 + \left(\frac{\partial\lambda}{\partial\theta_2}\right)^2 (\Delta\theta_2)^2\right]^{1/2}, \tag{2}$$

In the equation, $(\partial\lambda/\partial\theta)$ is the angular chromatic dispersion; $\Delta\theta$ is the variation value of the angle of incidence or emergence angle of the light beam. According to Eq. (3), if a certain

method can upgrade the laser beam straightening effect in a Littman cavity, the laser output frequency band can be compressed and narrowed. Moreover, some shortcomings in the Littman cavity can also be avoided; in other words, the narrowing of the laser output frequency band is achieved at a penalty: increasing the intracavity diffraction loss. References [6,7] apply the insertion of a cylindrical surface focusing lens into the cavity or expansion of the beam system to straighten the light beam, thus achieving the purpose of narrowing the laser output frequency band. Notwithstanding that these methods are also effective, however, they have drawbacks of increasing the intracavity absorption losses, inconvenient tuning, and the inability to attain the output of a single transverse mode.

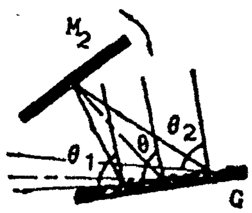

Fig. 1 Detail of the optical path between a grazing-incidence grating *G* and a tuning fully reflecting mirror *M*2

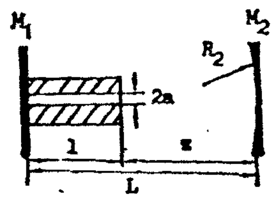

Fig. 2 A hollow circular dielectric waveguide laser cavity

As shown in Fig. 2, the hollow circular waveguide resonant oscillator can have the mode function of an intracavity can use a set of orthogonal normalization vectors V to indicate the mode function of the intrinsic mode of an intracavity waveguide.

$$TV = AV \tag{3}$$

In the equation, T is the compound conversion matrix for one

round-trip in the cavity; A is its intrinsic value. For the first time, the authors applied the matrix nondiagonal analytical method in calculation to indicate the following [8]: after inserting a proper hollow circular waveguide into the laser cavity, it was found that the waveguide can have the functions of controlling the mode and straightening the light beam in the resonant oscillator; in addition, the energy of higher-order modes in the cavity can be coupled into the energy of lower-order modes, thus considerably upgrading the oscillation output of the single-transverse-mode laser in this kind of cavity.

II. Experimental Technique

In the experiments, the pumping source of the pulsed dye laser employs a double-frequency light (λ = 532nm) of a tunable Q Nd^{3+}:YAG laser with 10ns as the pulse duration, 4.2 to 6.4mJ as the output energy, and 1Hz as the pulsed frequency. Fig. 3 shows the structure of the laser cavity with a hollow circular waveguide. The concentration of rhodamine 6G is 2.9 x 10^{-4} mole; the graduation lines of grating G are 1800 lines per mm; the flash wavelength is 600micrometers; and the width is 40mm. For the output lens M_1, the transmissivity is 60 percent in the range between 500 and 620nm. The tunable resonant lens M_2 is the total-reflection lens. The length of the laser cavity is 200mm. In the experimental process, different sizes of hollow circular waveguides were used. It was found that a hollow circular waveguide of 80mm in length and 0.6mm aperture is most

suitable for the requirements of this experiment. If the aperture of the waveguide tube is too small, the intra-cavity diffraction loss is greater. However, if the aperture of the waveguide tube selected is too large, the effect of limiting the transverse mode and straightening the light beam can be attained. Therefore, for a pulsed dye laser with different structures and increment of the resonance oscillator cavity, hollow circular waveguides with different aperture and length should be selected in order to attain the optimal effect of limiting the transverse mode and straightening the light beam. The adjustment steps of a Littman cavity with a hollow circular waveguide are as follows:

(1) By using an output lens M_1 and a total-reflection lens M_2 to constitute a flat-flat laser cavity, make adjustments so that the outputted laser attains the highest power. (2) Insert a hollow circular waveguide with 0.6mm as the aperture and 80mm as its length into the cavity nearing the output lens M_1, carefully adjust waveguide 2 so that not only is the laser output energy at a maximum, and at the same time the outputted laser should be a bright light spot at the far field. (3) Remove the reflection lens M_2 at the side in the absence of the waveguide tube, then according to Fig. 3, place the grating G and tunable total-reflection lens M_2. Adjust G and M_2 so that the laser is outputted as a bright light spot at the far field. Used in the experiment, a plane Fabry-Perot standard device is to analyze the frequency band of the outputted laser. Use a camera to record the interference fringes on the focal plane of the Fabry-Perot

standard device. Then use an automatic recording and scanning blackbody detector to record and analyze.

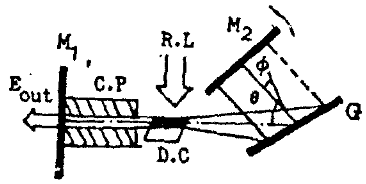

Fig. 3 Schematic diagram of the Littman cavity with hollow circular dielectric waveguide
C. P.—a hollow circular dielectric waveguide of length =80 mm and internal diameter =0.6 mm

III. Experimental Results and Discussion

By using the conventional Littman cavity (taking the hollow circular waveguide C.P. in Fig. 3), only when $\theta > 85°18'$, there appear the interference fringes with alternating bright and dark bands on the focal plane of the plane Fabry-Perot standard device. In addition, measurements showed that the frequency band of the laser output was 12GHz (as shown in Fig. 4) when $\theta = 87°20'$. However, by using the Littman cavity with intracavity hollow circular waveguide (Fig. 3), when $\theta > 69°5'$, interference fringes with alternating bright and dark bands appear on the focal plane of the Fabry-Perot standard device. Moreover, measurements showed that the laser output frequency bandwidth was 2GHz (as shown in Fig. 5) when $\theta = 85°37'$. The free spectral region was 20GHz for the plane Fabry-Perot device used in this experiment. The discrimination limit is approximately 2GHz. Therefore, with respect to the Littman resonant oscillator cavity with intra-

cavity waveguide, the laser frequency bandwidth outputted from the cavity is certainly smaller than 2GHz only when the grazing-incidence angle $\theta > 85°37'$.

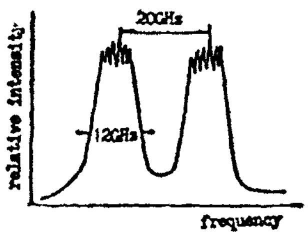

Fig. 4 Characteristic of laser output linewidth for a basic Littman cavity at the grazing incidence angle $\theta = 87°20'$

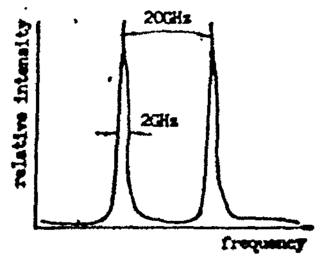

Fig. 5 Characteristic of laser output linewidth for a Littman cavity with a hollow circular dielectric waveguide at the grazing incidence angle $\theta = 85°37'$

(2) In the experiments, it was found that the laser output lightspot from the Littman cavity with intra-cavity hollow circular waveguide is a bright circular point; in other words, the laser output mode from the cavity is a single transverse-mode as shown in Fig. 6. In the case when the grating incidence angle varies within the range $60° \rightarrow 89°$, the output energy E_{out} from the pulsed dye laser varies within the range $1.12\,mJ \sim 290\,\mu J$. Generally, the laser output lightspot from a Littman cavity is not a bright circular point in the far field; that is, the laser output mode is a higher order transverse mode, as shown in Fig. 7. in the case when the grating incidence angle θ varies within the range $60° \rightarrow 89°$, the output energy E_{out} from this pulsed dye laser varies within the range $720\,\mu J \sim 44\,\mu J$.

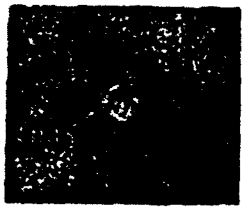

Fig. 6 The far-field pattern of dye laser for a Littman cavity with hollow circular dielectric waveguide

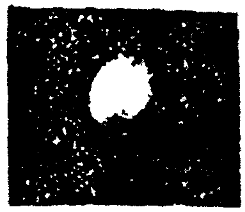

Fig. 7 The far-field pattern of dye laser for a basic Littman cavity

By comparing the measurement result in the experiments mentioned above, after inserting a hollow circular waveguide (with 0.6mm as the aperture and 80mm as the length) into a conventional Littman cavity, the output parameters of the pulsed dye laser are greatly improved, mainly shown as follows: for cases with the same grating incidence angle θ, a comparison of the Littman cavity with an intra-cavity hollow circular waveguide and a conventional Littman cavity shows that the former cavity can apparently have a higher laser energy output and can obtain a narrower laser output waveband than the latter cavity; in addition, the output mode of the former is also better. In the authors' view, the reasons for the improvements in these parameters are as follows: (i) after inserting an appropriate hollow circular waveguide into the conventional Littman cavity, since the laser oscillation mode in the resonant oscillation cavity changes into a single transverse mode from the previous higher-order transverse mode, therefore the straightening effect of intra-cavity light beam propagation is much greater. In this

case, the angular chromatic dispersions of the incident and the emergent light of the grating G in Fig. 1 become much smaller. In other words, the two quantities $(\partial\lambda/\partial\theta_1)^2(\Delta\theta_1)^2$ and $(\partial\lambda/\partial\theta_2)^2(\Delta\theta)^2$ in Eq. (3) are apparently smaller. As a result, in the case of a definite grating incident angle θ, because of the presence of the intra-cavity hollow circular waveguide, the laser output frequency band is obviously narrower. (ii) Since besides selection and control of the intra-cavity laser oscillation due to the hollow circular waveguide in the cavity, the laser energy of the higher-order transverse mode in the cavity can be coupled into laser energy of a lower-order transverse mode. The results show that after the hollow circular waveguide is inserted into the cavity, the laser output energy is not reduced as in the case when a small-hole diaphragm restricting the transverse mode is inserted in a conventional cavity, and the output energy even increases. The experimental results of the mutual coupling function between modes for a hollow circular waveguide in the resonant oscillator cavity are the same as those reported in reference [9,10].

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